Magnetic capture and the CV formation channel for AM CVn stars

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Wild stars in the Old West II, Tucson, March 17, 2009

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Outline

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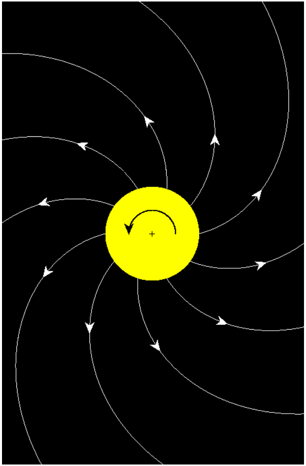
AM CVn stars

Properties

- $\sim$ 20 systems known
- Short orbital periods: 5–65 min
  - degenerate or semi-degenerate donor
  - low-frequency gravitational-wave sources
- Helium-dominated spectra
  - No traces of H found
  - H/He $\lesssim 10^{-5}$
- Possible donors
  - He/hybrid He-CO white dwarf
  - helium star
  - evolved main-sequence star

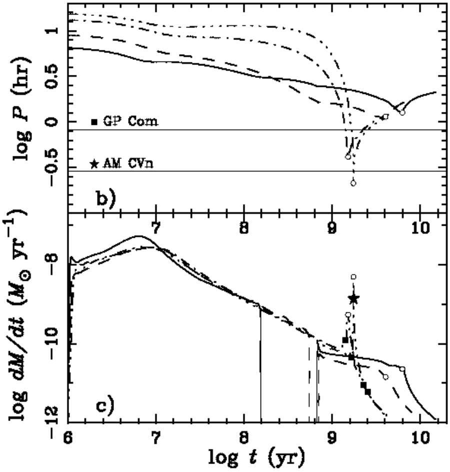
Magnetic capture



- Donor star fills Roche lobe around TAMS
- Magnetic braking on donor removes AM from orbit
- AM loss due to GWs takes over at short orbital periods
- Periods below 70–80 min possible

e.g. Pylyser & Savonije 1988,89, Podsiadlowski et al., 2002,03, van der Sluys et al., 2005a,b

Podsiadlowski et al., 2003



Podsiadlowski et al., 2003

- MB: Verbunt & Zwaan, 1981; Rappaport, Verbunt & Joss, 1983
- $M_{\rm WD}$: $0.6 - 1.0\, M_\odot$
- $M_{2,\rm i}$: $0.8 - 1.4\, M_\odot$
- $t_{\rm RLOF} \sim 7 - 11$ Gyr
- $t_{P_{\rm min}} \sim$ few Gyr
- $P_{\rm min}$ down to ~ 10 min
- $X_{\rm H} \sim 1 - 20\%$

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Binary-evolution models

- Eggleton's *TWIN* binary-evolution code (Eggleton 1971, 1972, etc., Pols et al., 1995)
- MB: Rappaport, Verbunt & Joss, 1983; $\gamma = 4$:
  - MB decreases as $\exp\left(1 - \frac{0.02}{q_\mathrm{conv}}\right)$ for $q_\mathrm{conv} \equiv \frac{M_\mathrm{conv}}{M_*} < 0.02$ (Podsiadlowski et al., 2002)
  - No MB if $q_\mathrm{conv} = 1$
- Analytic GW evolution after P_min
- Mass transfer fully non-conservative
- $M_\mathrm{WD} = 1.0\,M_\odot$; $M_{2,i} = 0.7 - 1.5\,M_\odot$
- $P_\mathrm{i} \sim 0.4 - 5.5$ days; $\sim$20–40 models per $M_\mathrm{2,i}$

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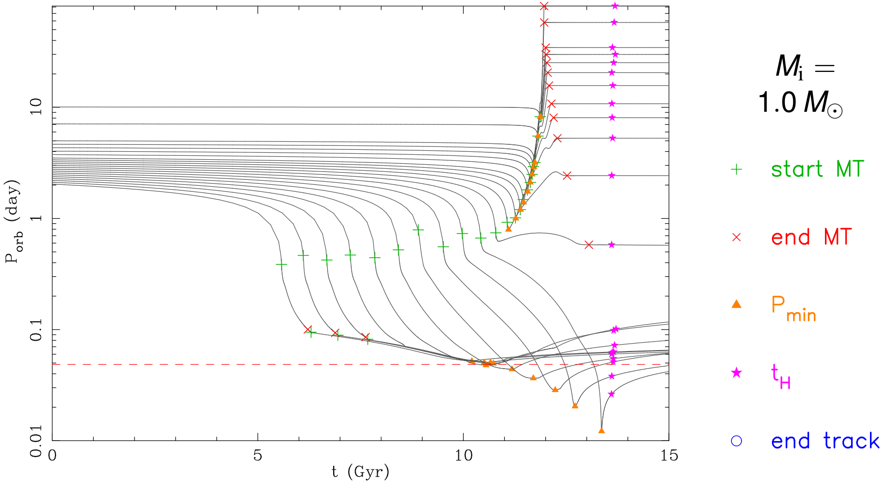
Period evolution



van der Sluys et al., in preparation

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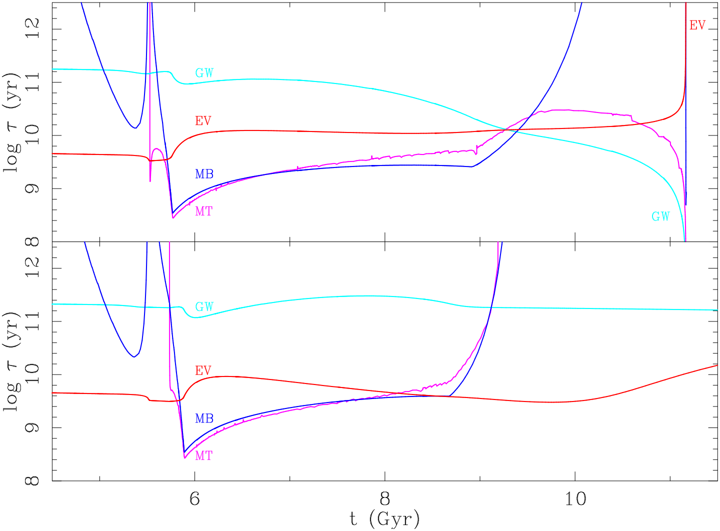
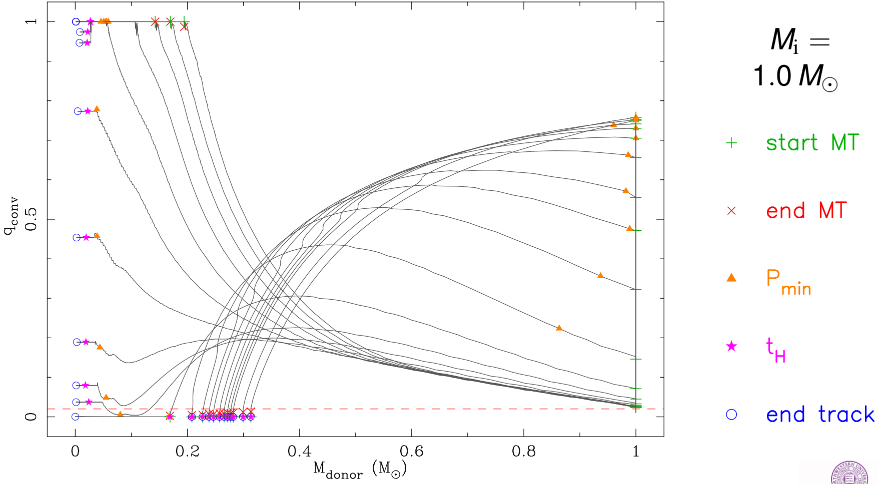
Timescales



van der Sluys et al., 2005

Convective mass fraction



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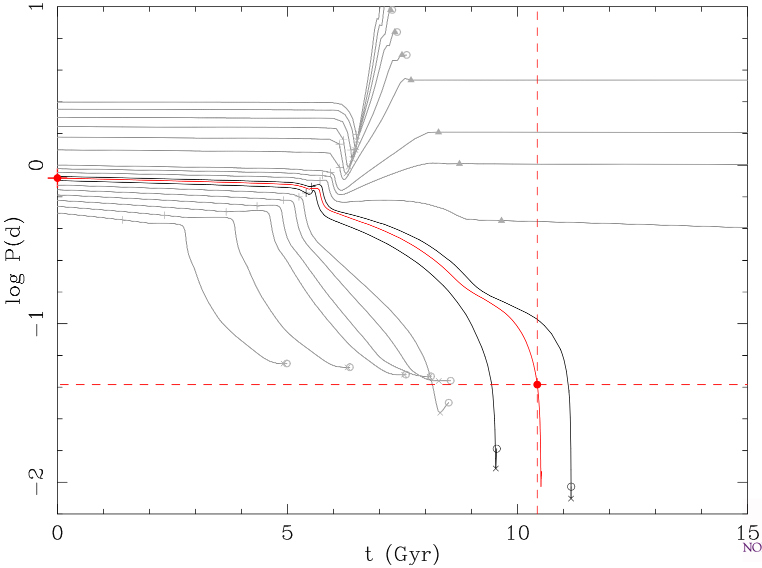
Interpolation of $t - \log P$ tracks



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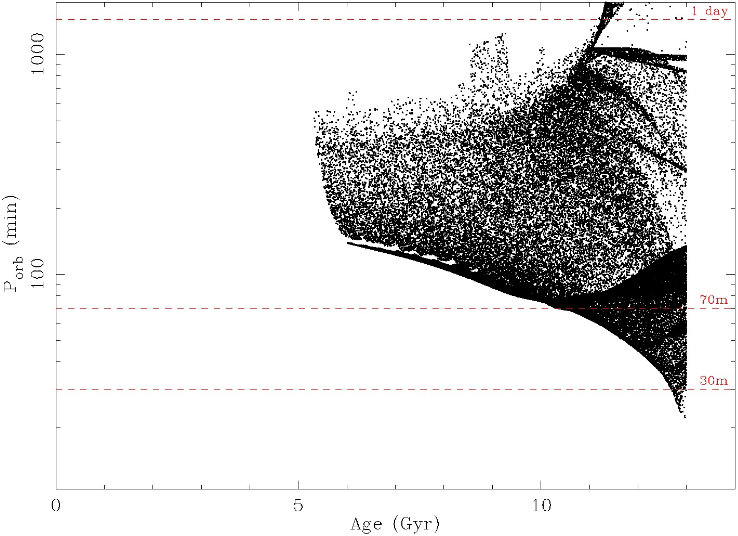
Monte-Carlo simulation



$M_i = 1.0\,M_\odot$

10^6 binaries

$0.5\,\mathrm{day} \lesssim P_i \lesssim 5.5\,\mathrm{day}$

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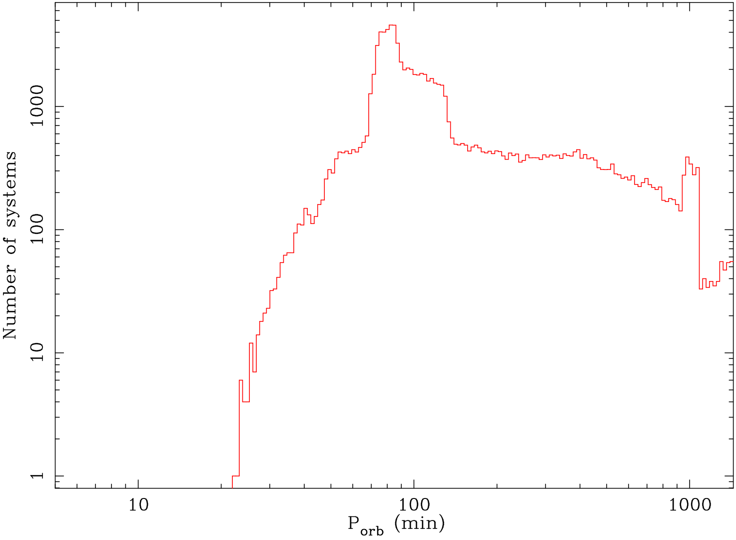
Period histogram



$M_{\rm i} =$
$1.0\ M_\odot$

10^6
binaries

$0.5\,\mathrm{day} \lesssim$
$P_{\rm i} \lesssim$
$5.5\,\mathrm{day}$

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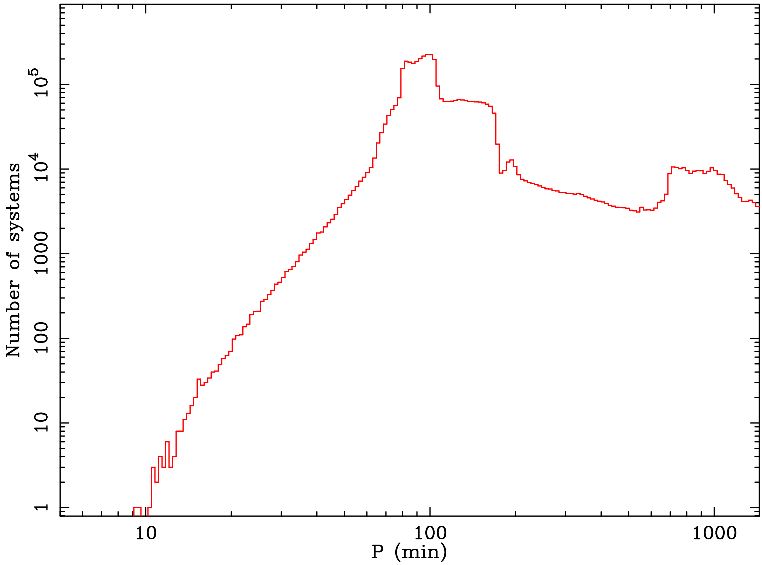
Combined period histogram



$M_\mathrm{i} = 0.7 - 1.5\,M_\odot$

9×10^6 initial binaries

$0.4\,\mathrm{day} \lesssim P_\mathrm{i} \lesssim 5.5\,\mathrm{day}$

4.1×10^6 CVs

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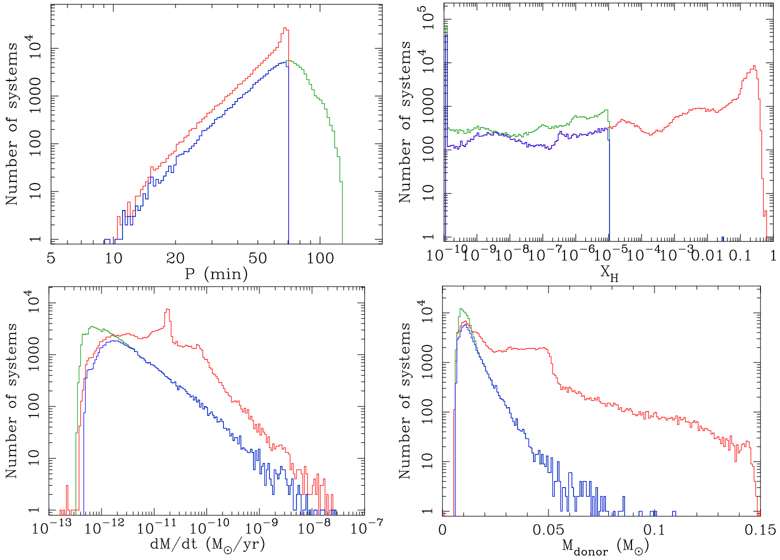
Ultra-compact/AM CVn population



$P < 70$ min: 174,448 sys

$X_H < 10^{-5}$: 103,900 sys

$P < 70$ min, $X_H < 10^{-5}$: 61,713 sys

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Choice of magnetic-braking prescription

Rappaport, Verbunt & Joss

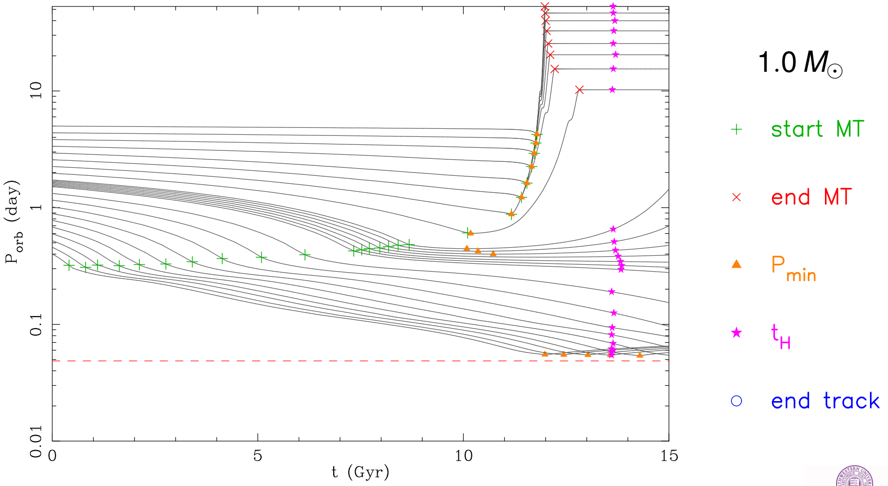
$$\frac{dJ_{\rm MB}}{dt} = -3.8 \times 10^{-30}\, \eta \left(\frac{M}{M_\odot}\right)\left(\frac{R}{R_\odot}\right)^4 \omega^3 \quad {\rm dyn\,cm}$$

Sills et al., 2000; Andronov et al., 2003

$$\begin{aligned} \frac{dJ_{\rm MB}}{dt} &= -K\left(\frac{R}{R_\odot}\right)^{0.5}\left(\frac{M}{M_\odot}\right)^{-0.5} \omega^3, & \omega \leq \omega_{\rm crit} \\ &= -K\left(\frac{R}{R_\odot}\right)^{0.5}\left(\frac{M}{M_\odot}\right)^{-0.5} \omega\, \omega_{\rm crit}^2, & \omega > \omega_{\rm crit} \end{aligned}$$

$$K = 2.7 \times 10^{47}\, {\rm g\,cm^2\,s}; \quad \omega_{\rm crit} = \omega_{{\rm crit},\odot} \frac{\tau_{{\rm to},\odot}}{\tau_{\rm to}}; \quad \omega_{{\rm crit},\odot} \approx 2.5\, {\rm day}$$

Saturated magnetic braking



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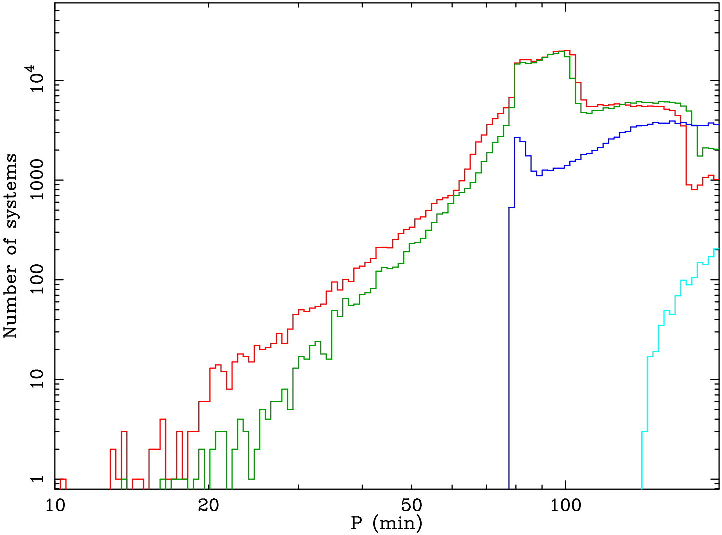
Effect of magnetic-braking prescription



Rappaport, Verbunt & Joss; $\eta = 1.00$

Rappaport, Verbunt & Joss; $\eta = 0.25$

Andronov et al.

GW only

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Conclusions & to do

Conclusions

- With the magnetic-capture scenario, a relatively large number of ultra-compact CVs can be produced
- A sizable fraction of these have $X_{\mathrm{H}} < 10^{-5}$ and would be observed as AM CVn stars
- If H-poor, ultra-compact CVs would be observed as AM CVns, we would expect many H-rich systems
- A saturated magnetic-braking prescription increases the minimum period found from ~ 10 min to ~ 75 min

To do

- Expand range of WD-accretor masses
- Convert relative numbers to absolute number of systems in the Galaxy
- Find observable distinction between He-WD channel and CV-channel AM CVn stars